HEAT RESISTING STEEL, GAS TURBINE USING THE STEEL, AND COMPONENTS THEREOF

Background of the Invention

The present invention relates to a novel heat resisting steel, a gas turbine using the steel, and various members of the gas turbine.

At present, a Cr-Mo-V steel, and 12Cr-Mo-Ni-V-N steel have been used in a disc for a gas turbine. In recent years, from a standpoint of energy saving, there has been a demand for enhancement of a thermal efficiency of the gas turbine. When power is generated with a high efficiency, a fossil fuel can be saved, an emission amount of an exhaust gas can be reduced, and this can contribute to global environment preservation. Most effective means for enhancing the thermal efficiency is to raise a gas temperature and pressure. When the gas temperature is raised to an order of 1500°C from an order of 1300°C, a great efficiency enhancement can be anticipated. Even when a combustion temperature does not rise, a part of an amount of compressed air for use in cooling the members is saved, and accordingly the efficiency enhancement can be anticipated.

However, with the increase of the temperature/pressure, the conventional Cr-Mo-V steel and 12Cr-Mo-Ni-V-N steel have insufficient strength, and materials having higher strengths are required. As the strength, a creep rupture strength which influences

high-temperature characteristics most is required. Moreover, for a gas turbine disc, a high tensile strength and high toughness are also required as well as the creep strength, and especially embrittlement has to be inhibited from occurring at the high temperature during the use.

As a structural material having a high creep rupture strength, austenitic steel, Ni-base alloy, Co-base alloy, martensitic steel, and the like have generally been known. The Ni-base alloy and Co-base alloy are not preferable from the standpoint of hot workability, machinability, and vibration damping property. The austenitic steel does not have a very high strength at around 400 to 450°C, and is not preferable in a whole gas turbine system. On the other hand, the martensitic steel has satisfactory matching with another corresponding component, and also has a sufficient high-temperature strength.

In JP-A-2001-49398, a heat resisting steel having high strength and toughness has been disclosed as a high/low pressure integral type steam turbine rotor. Further in JP-A-11-209851, PCT/JP97/04609, and JP-A-10-251809, a heat resisting steel for a gas turbine disc material has been disclosed.

However, the heat resisting steels disclosed in the publications cannot satisfy especially the high creep rupture strength and embrittlement reduction at the same time among the characteristics such as the

high creep rupture strength, high tensile strength, high toughness, and embrittlement reduction, and are not sufficient as the gas turbine disc having a higher efficiency. Only with the use of the conventional material simply having the high strength against the high temperature/pressure of the gas turbine, the gas temperature cannot further rise. When a high-temperature portion is cooled by a large amount of cooling air, further rise of the gas temperature can be anticipated, but thermal efficiency remarkably drops. Therefore, cooling air needs to be saved in order to prevent the drop of the thermal efficiency, but the saving is impossible until the above-described high material characteristics are obtained. Moreover, in general, when the high-temperature strength is enhanced, the toughness is lowered, and it is therefore difficult to achieve both the characteristics at the same time.

Brief Summary of the Invention

An object of the present invention is to provide a heat resisting steel which has high creep rupture strength to be capable of handling a higher temperature and which has high toughness even after heating at a high temperature for a long time, a gas turbine using the heat resisting steel, and various components of the gas turbine.

According to one aspect of the present invention, there is provided a heat resisting

martensitic steel comprising, by weight, 0.05 to 0.30% C, not more than 0.50% Si, not more than 0.60% Mn, 8.0 to 13.0% Cr, 0.5 to 3.0% Ni, 1.0 to 3.0% Mo, 0.1 to 1.5% tungsten (W), 0.5 to 4% Co, 0.05 to 0.35% vanadium (V), 0.02 to 0.30% in total of one or two elements selected from the group consisting of Nb and Ta, and 0.02 to 0.10% nitrogen (N), wherein a value of the square of a difference between the Ni amount and the Co amount, and the Ni amount are not more than values determined by a straight line drawn on a point A (1.0, 2.7%) and a point B (2.5, 1.0%) in the orthogonal coordinates shown in the attached drawing of Fig. 2 which represents a relationship between the above square value and the Ni amount, and wherein an amount ratio of Mo/(Mo + 0.5W) is not less than 0.5. Preferably, the above square value is not more than 1.8.

According to one feature of the martensitic steel of the invention having the above chemical composition, an amount ratio of W/Mo, and the Mn amount are not more than values determined by a straight line drawn on a point C (1.3, 0.15%) and a point D (2.5, 0.37%) in the orthogonal coordinates shown in the attached drawing of Fig. 4 which represents a relationship between the amount ratio and the Mn amount.

According to another feature of the martensitic steel of the invention having the above chemical composition, an amount ratio of Mo/(Mo + 0.5W), and the Mn amount are not less than values determined

by a straight line drawn on a point E (0.25, 0.4%) and a point F (0.7, 0.15%) in the orthogonal coordinates shown in the attached drawing of Fig. 6 which represents a relationship between the amount ratio and the Mn amount.

The invention steel may comprise, by weight, at least one element of not more than 1.5% Re and 0.001 to 0.015% boron (B). The invention steel may comprise, by weight, at least one element selected from the group consisting of not more than 0.5% Cu, not more than 0.5% Ti, not more than 0.2% Al, not more than 0.1% Zr, not more than 0.1% Hf, not more than 0.01% Ca, not more than 0.01% Mg, not more than 0.01% yttrium (Y), and not more than 0.01% of a rare earth element.

Preferably, the invention heat resisting steel is adjusted to have such a chemical composition that the Cr-equivalent, as defined by the following equation, is not more than 10, and the steel does not essentially contain the δ ferrite phase:

the Cr-equivalent = Cr+6Si+4Mo+1.5W+11V+5Nb-40C-30N-30B-2Mn-4Ni-2Co+2.5Ta (where each element is of a content, by weight %, of the heat resisting steel).

The invention steel preferably has not less than 1180 MPa of tensile strength at room temperature, more preferably not less than 1200 MPa, not less than 420 Mpa of creep rupture strength at 510°C for 10^5 hours, more preferably not less than 430 Mpa, and not less than 19.6 J/cm^2 of a V-notch Charpy impact value at 25°C

after heating at 530°C for 10^4 hours.

According to another aspect of the present invention, there is provided a gas turbine comprising:

a turbine stub shaft;

a plurality of turbine discs connected to the turbine stub shaft by turbine stacking bolts via turbine spacers;

turbine blades each implanted in the respective disc to rotate by high-temperature combustion gas generated in a combustion device;

a distant piece connected to the turbine discs;

a plurality of compressor rotors connected to the distant piece;

compressor blades which are implanted to compressor discs constituting the respective compressor rotor, and which compress air; and

a compressor stub shaft connected to the compressor rotors, wherein

at least one of the turbine discs, the distant piece, the turbine spacers, the compressor disc at a last stage, and the turbine stacking bolts is made of the above heat resisting steel.

According to still another aspect of the present invention, there is provided a disc for a gas turbine, which is a disc member comprising a circumferential implanting section for a turbine blade, and a plurality of bores receiving a plurality of

stacking bolts by which a plurality of the disc members are integrally fastened to one another, wherein the disc is made of the heat resisting steel having the above chemical composition and properties. The disc member may have optionally a central bore.

The gas turbine disc should have high fatigue strength as well as high tensile strength in order to bear high centrifugal stress and vibration stress due to high-speed rotation. If the gas turbine disc has a metal structure containing the detrimental delta (δ) ferrite, the fatigue strength is excessively deteriorated. Therefore, the Cr-equivalent is so adjusted to be not more than 10 that the steel has an entire temper martensite structure.

According to still another aspect of the present invention, there is provided a gas turbine distant piece which is a cylindrical member comprising protrusions provided at both opposite ends of the cylindrical member; a plurality of bores in one of the protrusions, which receive a plurality of stacking bolts by which the cylindrical member is integrally fastened to turbine discs, and a plurality of other bores in the other protrusion, which receive a plurality of other stacking bolts by which the cylindrical member is integrally fastened to compressor discs, wherein the gas turbine distant piece is made of the above heat resisting steel having the same properties as mentioned above.

According to still another aspect of the present invention, there are provided gas turbine compressor discs each of which is a disc member comprising a circumferential implanting section for compressor blades, and a plurality of bores receiving a plurality of stacking bolts by which a plurality of the disc members are integrally fastened to one another, wherein the gas turbine compressor discs are made of the above heat resisting steel having the same properties as mentioned above.

According to still another aspect of the present invention, there is provided a gas turbine stacking bolt which is a bar member comprising a screw portion at one end thereof, and a polygonal head portion at the other end, wherein the gas turbine stacking bolt is made of the above heat resisting steel having the same properties as mentioned above.

Other objects, features and advantages of the invention will become apparent from the following description of the embodiments of the invention taken in conjunction with the accompanying drawings.

Brief Description of the Several Views of the Drawings

FIG. 1 is a graph showing a relationship between creep rupture strength and a value of the square of a difference between the Ni amount and the Co amount;

FIG. 2 is a graph showing a relationship

between the Ni amount and the square value, in which the line represents a steel having not less than 420 MPa of creep rupture strength at 510°C for 10^5 hours on the basis the relationship shown in FIG. 1;

FIG. 3 is a graph showing a relationship between a V-notch Charpy impact value at 25°C and an amount ratio of W/Mo after an embrittle treatment;

FIG. 4 is a graph showing a relationship between the ratio of W/Mo and the Mn amount, in which the line represents a steel having not less than 19.6 J/cm^2 of a V-notch Charpy impact value at 25°C after the embrittle treatment;

FIG. 5 is a graph showing a relationship between the V-notch Charpy impact value at 25°C and an amount ratio of Mo/(Mo + 0.5W) after the embrittle treatment;

FIG. 6 is a graph showing a relationship between the amount ratio of Mo/(Mo + 0.5W) and the Mn amount, according to which line not less than 19.6 J/cm^2 of the V-notch Charpy impact value at 25°C is obtained after the embrittle treatment;

FIG. 7 is a sectional view of a rotary section of a gas turbine according to the present invention.

Detailed Description of the Invention

Reasons for limitations on component range of heat resisting steel of the present invention will be

described.

A carbon (C) content is set to not less than 0.05% in order to obtain high tensile strength and yield strength. However, if the C amount exceeds 0.30%, the metal structure becomes unstable when exposed to high temperature for a long time, a creep rupture strength and toughness are deteriorated. Therefore, the content is set to not more than 0.30%, especially preferably 0.07 to 0.23%, more preferably 0.10 to 0.20%.

Si is a deoxidizer, and Mn is a desulfurizing/deoxidizing agent. These are added at the time of melting of heat resisting steel, and are effective even in small amounts. Si is a δ ferrite generating element. When a large amount of this element is added, detrimental δ ferrite is generated to lower fatigue strength and toughness. Therefore, the content is set to 0.50% or less. It is to be noted that Si does not have to be added in a carbon vacuum deoxidizing process and electro slag remelting process, and no Si is preferably added. The content is especially preferably 0.10% or less, more preferably 0.05% or less.

When a small amount of Mn is added, the toughness is enhanced. However, when a large amount is added, the toughness is lowered. Therefore, the content is set to 0.60% or less. Especially, since Mn is effective as the desulfurization agent, the content is preferably 0.30% or less, especially preferably

0.25% or less, further preferably 0.20% or less from the standpoint of enhancement of the toughness. The content of 0.05% or more is preferable from the standpoint of the toughness.

Cr enhances corrosion resistance and tensile strength, but with an addition amount exceeding 13%, a δ ferrite structure is generated. When the amount is smaller than 8%, the corrosion resistance and high-temperature strength are insufficient, and therefore the content of Cr is set to 8 to 13%. The content is especially preferably 10.0 to 12.8%, more preferably 10.5 to 12.5%.

Mo is effective in improving the creep rupture strength by virtue of solid-solution strengthening and precipitation strengthening with carbide/nitride. When the Mo content is not more than 1.0%, Mo has an insufficient effect of enhancing the creep rupture strength. When the Mo content is not less than 3%, delta (δ) ferrite is generated. Therefore, the Mo content is set to 1.0 to 3.0%, preferably 1.2 to 2.7%, more preferably 1.3 to 2.5%.

W has an effect similar to that of Mo. For a higher strength, the content may be equal to that of Mo. With a content of 0.1% or less, W has an insufficient effect of enhancing the creep rupture strength. With a content exceeding 1.5%, the toughness is lowered, and therefore the content is set to 0.1 to 1.5%. The content is preferably 0.2 to 1,4%, more preferably 0.3

to 1.3%.

Since Co enhances the strength at a higher temperature, the content is preferably increased with the increase of the temperature. With a content less than 0.5%, the effect is not sufficient. With a content exceeding 4.0%, heating embrittlement is promoted, and therefore an upper limit is set to 4%. The content is preferably 0.8 to 3.5%.

V and Nb precipitate carbide, enhance the tensile strength, and further have an effect of enhancing the toughness. With not more than 0.05% V, or not more than 0.02% Nb, the effect is insufficient. From the standpoint of reduction of δ ferrite generation, not more than 0.35% V, and not more than 0.3% Nb are preferable. Especially, the content of V is preferably 0.15 to 0.30%, more preferably 0.20 to 0.30%. The content of Nb is 0.04 to 0.22%, more preferably 0.10 to 0.20%. Instead of Nb, Ta can be added in the same manner, and a total amount is similar to the content even in composite addition.

Ni enhances low-temperature toughness, and also has an effect of preventing δ ferrite from being generated. This effect is preferable with not less than 0.5% Ni, and the effect is saturated with an addition amount exceeding 3.0%. When a large amount of Ni is added, the creep rupture strength is lowered. The content is preferably 0.5 to 2.5%, more preferably 0.7 to 2.3%.

N is effective in enhancing the creep rupture strength and in preventing δ ferrite from being generated. However, the effect is insufficient with a content less than 0.02%, and the toughness is lowered with a content exceeding 0.10%. Especially, superior properties are obtained in a range of 0.04 to 0.080%.

Re is effective in improving the creep rupture strength by virtue of solid-solution strengthening. Since an excess addition promotes the embrittlement, an addition amount of not more than 2% is preferable. However, since Re is a rare element, a content of not more than 1.5% is preferable in a practical use, more preferably not more than 1.2%.

B has a function of enhancing a grain boundary strength, and has an effect of enhancing the creep rupture strength. This effect is insufficient with a content of not more than 0.001%, and the toughness drops with an addition amount exceeding 0.015%. The content is especially preferably 0.002 to 0.008%.

The reduction of P and S has an effect of enhancing the low-temperature toughness without impairing the creep rupture strength, and the reduction to the utmost is preferable. From the standpoint of the enhancement of the low-temperature toughness, not more than 0.015% phosphor (P), not more than 0.015% sulfur (S) are preferable. Especially, not more than 0.010% phosphor (P), not more than 0.010% sulfur (S)

are preferable.

The reduction of Sb, Sn, and As also has the effect of enhancing the low-temperature toughness, and the reduction to the utmost is preferable, but from the standpoint of an existing steel making technique level, the content is limited to not more than 0.0015% Sb, not more than 0.01% Sn, and not more than 0.02% As. Especially, not more than 0.001% Sb, 0.005% Sn, and not more than 0.01% As are preferable.

At least one of MC carbide forming elements such as Ti, Al, Zr, Hf, Ta is preferably contained by not more than 0.5% in total. The content of Al, which is used as a deoxidizer and a grain refiner, is set to not less than 0.0005%. If the Al content exceeds 0.2%, nitrogen, which is effective for improving the creep strength, is fixed to deteriorate the creep rupture strength. Thus, the Al content is preferably not more than 0.2%.

The present inventors turned their attention to a content balance of additive Ni and Co. Accordingly, a value of the square of a difference between the Ni amount and the Co amount, and the Ni amount have been set to be not more than values determined by a straight line drawn on a point A (1.0, 2.7%) and a point B (2.5, 1.0%) in the orthogonal coordinates shown in the attached drawing of Fig. 2 which represents a relationship between the above square value and the Ni amount, and an amount ratio of Mo/(Mo + 0.5W) is set to

be not less than 0.5, whereby the above properties can be obtained. Especially, remarkable properties can be obtained when the tungsten (W) amount is not more than 1.5%. Further, the above square value is preferably set to be not more than 1.8. If the tungsten (W) amount exceeds 1.5%, the high creep strength mentioned above can be obtained, but the toughness is deteriorated after heating at high temperature for a long time. Thus, more than 1.5% tungsten (W) is not preferable.

Ni and Co contribute to improving martensitic steel in toughness. Ni is effective for improving the toughness, but deteriorates the creep strength. Co is effective for improving the creep strength, but promotes embrittlement of the steel during operation, and deteriorates the toughness. Therefore, since the toughness and creep strength are kept and the heating embrittlement is inhibited, it has been found that the difference between the Ni amount and the Co amount is an effective index indicating a preferable balance between the additive amounts of Ni and Co in the present invention.

Further, in the present invention, an amount ratio of W/Mo, and the Mn amount are set to be not more than values determined by a straight line drawn on a point C (1.3, 0.15%) and a point D (2.5, 0.37%) in the orthogonal coordinates shown in the attached drawing of Fig. 4 which represents a relationship between the

amount ratio and the Mn amount. Accordingly, a high toughness is obtained even after the heating at high temperature for the long time.

Further, in the present invention, an amount ratio of Mo/(Mo + 0.5W), and the Mn amount are set to be not less than values determined by a straight line drawn on a point E (0.25, 0.4%) and a point F (0.7, 0.15%) in the orthogonal coordinates shown in the attached drawing of Fig. 6 which represents a relationship between the amount ratio and the Mn amount. Accordingly, the high toughness is obtained especially even after the heating at high temperature for the long time.

That is, in the present invention, also for the addition of Mo and W, it has been found that a specific ratio of both the addition amounts is an effective index indicating a preferable balance. As the elements contributing to improvement of high-temperature strength of martensitic steel, Mo and W function as a solid-solution strengthening element, respectively, and the effect is represented by the Mo-equivalent = (Mo(%)+0.5W(%)) or the amount ratio of W/Mo. However, these elements lower the toughness after the heating at high temperature for the long time, but a small amount of Mn performs an important function of enhancing the toughness after the heating at high temperature for the long time, and the effect is remarkably obtained by a composite addition with a

specific content from the relation with the Mn amount. Mo and W are different from each other in the effect, the addition of W is more effective in enhancing the strength at the high temperature. However, when a ratio of W is large, the toughness tends to drop as described above.

Especially, the addition of W is effective under a use environment at a temperature exceeding 600°C, but a use temperature of the gas turbine disc is lower, and the high toughness is required. Therefore, the Mo addition is more preferable in the present invention. Therefore, when the amount ratio of (Mo/(Mo + 0.5W) is set to 0.5 or more, preferably 0.6 to 0.95, more preferably 0.75 to 0.95, the high toughness is obtained even after the heating at high temperature for the long time.

In a preferable thermal treatment of the material of the present invention, first the material is uniformly heated at a temperature sufficient for transformation to complete austenite, 1000°C at minimum, 1150°C at maximum, quenched (preferably oil cooling or water spraying), and subsequently heated/retained and cooled at a temperature of 540 to 600°C (primary tempering). Subsequently, the material is heated/retained and cooled at a temperature of 550 to 650°C (secondary tempering) to form an entirely tempered martensitic steel. The temperature of the secondary tempering is set to be higher than a primary tempering temperature.

When quenching, it is preferable to stop cooling just above an Mf point in order to prevent occurrence of cracks. Specifically, the above cooling-stop temperature is preferably not lower than 150°C. When conducting a primary tempering, the material is heated from the above temperature.

EMBODIMENTS

Example 1

Table 1 indicates a chemical composition (weight %) of heat resisting 12% Cr steel for a gas turbine disc material, and the balance is Fe. Each specimen was subjected to vacuum arc melting at 150 kg, heated at 1150°C, and forged to form a raw material. The raw material was heated at 1050°C for two hours and subsequently oil-cooled, heated at 560°C for five hours and subsequently air-cooled to be subjected to the primary tempering, and next heated at 580°C for five hours and furnace-cooled to be subjected to the secondary tempering. After the thermal treatment, a creep rupture specimen, tensile specimen, and V-notch Charpy impact specimen were sampled from the raw material, and used in experiments. An impact test was conducted with respect to the thermally treated material and a heated/embrittled material at 530°C for 10,000 hours. The embrittled material has conditions equal to those of a material heated at 510°C for 100 thousand hours on the basis of the Larson-Miller parameter.

Table 1

	C	Si	Mn	Ni	Cr	Mo	W	V	Nb	Co	N	Fe	$(Ni-Co)^2$	Mo/(Mo+0.5W)
1	0.12	0.01	0.13	2.7	11.4	1.9	0	0.19	0.06	0	0.036	Bal.	7.18	1.00
2	0.16	0.04	0.11	2.6	11.5	2.1	0	0.24	0.15	2.8	0.076	Bal.	0.04	1.00
3	0.10	0.06	0.60	0.3	10.2	0.2	2.8	0.20	0.07	2.5	0.020	Bal.	5.06	0.13
4	0.15	0.03	0.15	1.2	11.0	1.9	0.6	0.23	0.12	4.2	0.070	Bal.	9.00	0.86
5	0.12	0.03	0.15	3.2	10.2	1.5	0.8	0.23	0.12	1.1	0.068	Bal.	4.41	0.79
6	0.15	0.03	0.15	1.2	10.9	0.7	1.8	0.23	0.12	1.8	0.069	Bal.	0.36	0.44
7	0.10	0.03	0.15	1.0	11.0	1.9	0.3	0.23	0.12	2.2	0.070	Bal.	1.44	0.93
8	0.17	0.25	0.32	0.8	10.5	2.1	0.2	0.20	0.17	0.6	0.075	Bal.	0.04	0.95
9	0.19	0.10	0.10	2.2	11.0	1.3	1.2	0.29	0.08	1.8	0.052	Bal.	0.16	0.68
10	0.15	0.03	0.15	1.2	10.9	1.9	0.3	0.23	0.12	1.0	0.069	Bal.	0.04	0.93
11	0.11	0.03	0.40	1.2	10.9	1.1	1.4	0.23	0.12	1.0	0.064	Bal.	0.04	0.61
12	0.11	0.03	0.40	2.6	10.9	1.1	1.4	0.23	0.12	3.3	0.061	Bal.	0.49	0.61
13	0.14	0.03	0.15	1.2	10.9	1.5	0.8	0.23	0.11	1.0	0.071	Bal.	0.04	0.79

Table 2 shows mechanical properties of these specimens. Specimen Nos. 7 to 13 are of the invention steel exhibiting not less than 1180 MPa of tensile strength at room temperature which is required for a high-temperature/high-pressure gas turbine disc material, not less than 420 MPa of creep rupture strength at 510°C for 10^5 hours, and not less than 19.6 J/cm^2 of the V-notch Charpy impact value at 25°C after embrittle treatment. It has been confirmed that the specimens are sufficiently satisfactory. On the other hand, Specimen Nos. 1 to 6, which are of comparative steel, cannot simultaneously satisfy mechanical properties required for the high-temperature/pressure gas turbine disc material. For any one of Specimen Nos. 1, 3, 4, and 5 which are of comparative steel, the above square value increases, and this indicates that the addition amount of one of Ni and Co is large. For Comparative Specimen Nos. 1 and 5 having a large Ni addition amount, the tensile strength and the V-notch Charpy impact value at 25°C before/after the heating embrittlement are satisfied, but the creep strength cannot be satisfied. For Comparative Specimen Nos. 3 and 4 having a large Co addition amount, the creep rupture strength is satisfied, but the V-notch Charpy impact value at 25°C after the heating embrittlement is remarkably deteriorated.

Specimen Nos. 3 and 6 in which the amount ratio of Mo/(Mo + 0.5W) of an Mo-equivalent is less

than 0.5 have a low impact value. Specimen No. 2 to which Mo alone is added (the W amount = 0) has a low creep rupture strength.

Table 2

	Tensile strength (MPa)	0.2% Yield strength (MPa)	Elongation (%)	Reduction of area (%)	Rupture strength at 510°C for 10^5 hours (Mpa)	Impact value (J/cm²)	
						Before embrittlement	After embrittlement
1	1222	1063	19.2	78.1	336	114.2	72.2
2	1315	1144	18.1	75.6	344	98.1	42.2
3	1024	891	17.2	71.3	438	10.2	6.2
4	1243	1081	19.2	74.6	421	42.3	5.3
5	1189	1034	17.5	78.6	338	74.3	31.2
6	1230	1070	16.5	65.1	431	48.1	11.4
7	1210	1053	18.7	73.2	429	45.3	22.1
8	1237	1076	17.5	73.4	442	58.5	35.6
9	1250	1088	19.2	76.2	445	69.1	41.2
10	1223	1064	18.8	74.9	440	49.2	26.4
11	1232	1072	18.8	75.2	433	48.1	28.5
12	1240	1079	17.9	74.6	428	72.4	27.4
13	1245	1021	18.3	73.8	430	45.6	24.5

Furthermore, the specimens of the chemical compositions shown in Table 3 were manufactured by the melting and forging, and subjected to the same thermal treatment for use in the experiments. The test results are shown in Table 4. As shown in Table 4, for Specimen Nos. 17 to 19 which are the present invention materials, it has been confirmed that the properties are obtained so as to sufficiently satisfy the room temperature tensile strength required for the high-temperature/pressure gas turbine disc material of not less than 1180 MPa, the creep rupture strength at 510°C for 10^5 hours of not less than 420 MPa, and the V-notch Charpy impact value at 25°C after the embrittle treatment of not less than 19.6 J/cm^2. On the other hand, for Specimen Nos. 14 and 15 of the comparative materials to which B is excessively added, elongation and impact value of the tensile test are low, and the mechanical properties required for the high-temperature/pressure gas turbine disc material cannot simultaneously be satisfied. Specimen No. 14 of the comparative material to which Mo is added alone (the W amount = 0) has a slightly low creep strength. The Specimen No. 16 of the comparative material to which Re is excessively added has a sufficient creep strength, but a value of drawing is low.

Table 3

	C	Si	Mn	Ni	Cr	Mo	W	V	Nb	Co	N	B	Re	Fe	$(Ni-Co)^2$	Mo/(Mo+0.5W)
14	0.16	0.03	0.15	1.1	11.0	1.9	0	0.23	0.13	1.0	0.025	0.018	0.5	Bal.	0.01	1.00
15	0.15	0.03	0.15	1.2	11.0	1.1	0.8	0.23	0.12	1.5	0.045	0.025	0.6	Bal.	0.09	0.73
16	0.15	0.03	0.15	1.2	11.0	1.5	0.8	0.23	0.12	1.5	0.045	0.008	2.1	Bal.	0.09	0.79
17	0.18	0.03	0.10	1.9	11.0	2.1	0.5	0.23	0.12	0.8	0.070	0	0.2	Bal.	1.21	0.89
18	0.12	0.03	0.33	1.2	11.0	1.7	0.5	0.23	0.12	1.2	0.070	0	0.6	Bal.	0	0.87
19	0.15	0.03	0.15	1.2	11.0	1.9	0.3	0.23	0.12	1.0	0.020	0.010	0.8	Bal.	0.04	0.93

Table 4

	Tensile strength (MPa)	0.2% Yield strength (MPa)	Elongation (%)	Reduction of area (%)	Rupture strength at 510°C for 10^5 hours (Mpa)	Impact value (J/cm²)	
						Before embrittlement	After embrittlement
14	1198	1018	15.1	62.3	420	10.5	6.2
15	1254	1066	16.2	54.5	434	16.4	7.4
16	1254	1066	18.2	48.2	421	52.1	25.2
17	1241	1055	18.1	72.4	444	67.2	45.1
18	1217	1034	18.8	73.6	458	60.5	36.4
19	1221	1038	19.6	71.6	452	54.2	33.3

FIG. 1 is a diagram showing a relation between the creep rupture strength and the square of (difference between Ni amount and Co amount). As shown in FIG. 1, the creep rupture strength remarkably drops as the value of the square of a difference between the Ni amount and the Co amount increases. Especially, the relation with the Ni amount is large. When the Ni amount is 1.0 to 1.2%, the creep rupture strength is high as compared with an amount of 2.2 to 3.2%. However, with high Ni, when the square value increases, the creep rupture strength rapidly drops.

Especially, when the Co amount is larger than the Ni amount, the creep strength drops slightly, and an influence by the square value is small.

FIG. 2 is a linear diagram showing a relationship between the square value and the Ni amount having a creep rupture strength at 510°C for 10^5 hours of not less than 420 MPa from the relation of FIG. 1. As described above, for the creep rupture strength, the above square value has a close relation with the Ni amount. When the value represented by the relation between the square value and the Ni amount is set to be not more than the value determined by a straight line drawn on a point A (1.0, 2.7%) and a point B (2.5, 1.0%) in the orthogonal coordinates shown in the attached drawing of Fig. 2 which represents a relationship between the above square value and the Ni amount, a creep rupture strength of 420 MPa or more is

obtained.

FIG. 3 is a linear diagram showing a relation between the V-notch Charpy impact value at 25°C and an amount ratio of W/Mo after the embrittle treatment. As shown in FIG. 3, the impact value rapidly drops with an increase of the ratio of W/Mo. The impact value is high with a large Mn amount of 0.32 to 0.4% as compared with an amount of 0.15%, and is further high with a large C amount. Furthermore, the impact value remarkably drops with any Mn amount, when the ratio of W/Mo increases.

FIG. 4 is a linear diagram showing a relationship between the ratio W/Mo and the Mn amount having a V-notch Charpy impact value at 25°C of 19.6 J/cm^2 or more after the embrittle treatment. As shown in FIG. 4, when the value represented by the relation between the (W amount/Mo amount) ratio and the Mn amount is set to be not more than the value determined by a straight line drawn on a point C (1.3, 0.15%) and a point D (2.5, 0.37%) in the orthogonal coordinates shown in the attached drawing of Fig. 4 which represents a relationship between the amount ratio and the Mn amount, a 25°C V-notch Charpy impact value of not less than 19.6 J/cm^2 is obtained. It is to be noted that FIG. 4 is applied with a C amount of not more than 0.17%.

FIG. 5 is a linear diagram showing a relationship between the V-notch Charpy impact value at

25°C and an amount ratio of Mo/Mo + 0.5W) after the embrittle treatment. As shown in FIG. 5, when the ratio is further increased, the high toughness is obtained even after the heating at high temperature for the long time. The impact value is high with a large Mn amount of 0.32 to 0.4% as compared with an amount of 0.15%, and further with a large C amount, and increases as the ratio of Mo/(Mo + 0.5W) increases. When the Mn amount is 0.15%, a carbon amount is not more than 0.15%. When the Mn amount is 0.32 to 0.4%, the carbon amount is 0.11 to 0.17%.

FIG. 6 is a linear diagram showing a relationship between the amount ratio of Mo/(Mo + 0.5W) and the Mn amount in which a V-notch Charpy impact value at 25°C after the embrittle treatment of not less than 19.6 J/cm^2 is obtained. When the value represented by this relation is set to be not less than the value determined by a straight line drawn on a point E (0.25, 0.4%) and a point F (0.7, 0.15%) in the orthogonal coordinates shown in the attached drawing of Fig. 6 which represents a relationship between the amount ratio and the Mn amount, the above-described impact value is obtained. It is to be noted that FIG. 6 is applied with a carbon amount of 0.17% or less.

Example 2

FIG. 7 is a sectional view of a turbine upper half of an air compression type three-stage turbine including an air cooling system. As shown in FIG. 7, a

gas turbine of the present example is constituted of a casing 80, a compressor including a compressor rotor 2 and a blade array of an outer peripheral portion, a combustion unit 84, alternately arranged turbine nozzles 81 to 83 and turbine blades 51 to 53, a turbine rotor 1, and the like. The turbine rotor 1 includes three turbine discs 11, 12, 13 and a turbine stub shaft 4, and is closely bonded as a high-speed rotating member. The turbine blades 51 to 53 are disposed on the outer periphery of each turbine disc, connected to the compressor rotor 2 and turbine stub shaft via a distant piece 3, and rotatably supported by a bearing. In this constitution, air compressed by the compressor is used, and a high-temperature/pressure working gas generated by the combustion unit 84 expands while flowing. Accordingly, the turbine rotor 1 is rotated to generate a motive energy. A combustion gas flowing out of the turbine section is fed to an exhaust heat recovery boiler (HRSG) to produce steam.

Although there are also portions not shown, in addition to the above-described constitution, a main constitution of the gas turbine in the present embodiment includes the turbine stub shaft 4, turbine stacking bolts 5, turbine spacers 18, the distant piece 3, compressor discs 17 constituting a compressor rotor, compressor blades, compressor stacking bolts, and a compressor stab shaft. The compressor discs 17 are of not less than seventeen stages, and the turbine blades

are of three stages. The constitution can similarly be applied also with respect to four stages.

In the present embodiment, air compressed by the compressor is used to cool each component by a flow of air shown by an arrow in FIG. 7. Air flows in via an outer side wall in the first-stage turbine nozzle 81 and the second-stage turbine nozzle 82, and is exhausted from a blade section. The second-stage turbine nozzle 82 is cooled over an inner side wall. In the third-stage turbine nozzle 83, air flows in via the outer side wall, flows out of the inner side wall, and is exhausted to the outside via the spacer section. For the first-stage turbine blade 51, compressed air passes through the side wall from a central portion of the turbine disc 11. The air passes through a spacer 18 section and through cooling bores provided in the blade, and is exhausted via the tip end of the blade and a trailing portion of a blade section to cool both the blade and disc. In the blade, the combustion gas is sealed not to flow inside by a seal fin disposed in a shank portion. Similarly, in the second-stage turbine blade 52, air passes through the spacer 18 and the cooling bore provided in the blade from the turbine disc 12, and is exhausted via the tip end, and cooled. The third-stage turbine blade 53 does not include any cooling bore, but air passes through the side wall from the central portion of the turbine disc 13, passes through the seal fins to cool these fins, and enters

the exhaust heat recovery boiler together with the combustion gas. In the boiler, steam is formed as a power source of a steam turbine.

As the material for use in the turbine discs 11, 12, 13 in the present embodiment, a large-sized specimen including composition No. 1 shown in Table 1 of Example 1 was melted, heated at 1150°C, and forged to form an experiment material. The material was heated at 1050°C for eight hours and cooled with a blast air, and the cooling temperature was stopped at 150°C. The material was heated at 580°C for 12 hours and air-cooled to perform the secondary tempering. Next, the material was heated at 605°C for five hours, and furnace-cooled to perform the secondary tempering. A creep rupture specimen, tensile specimen, and V-notch Charpy impact test specimen were sampled from the material after the thermal treatment, and used in the experiments. The impact test of the thermally treated material was conducted with respect to the heated/embrittled material in the same manner as in Example 1. These properties in the present embodiment are equivalent to those of Example 1.

In the present example, any of the entirely tempered martensitic steel Nos. 7 to 13, Nos. 17 to 19 shown in Example 1 is usable in the distant piece 3 and turbine stacking bolt 5 in addition to the turbine discs 11, 12, 13.

Moreover, these martensitic steels have a

ferrite-based crystalline structure, but the ferrite-based material has a small thermal expansion coefficient as compared with an austenite-based material such as Ni-base alloy. When the heat resisting steel of the present embodiment is used in the turbine disc instead of the Ni-base alloy, the thermal expansion coefficient of the disc material is further small. Therefore, thermal stress generated in the disc is reduced, cracks are inhibited from being generated, and collapse can be reduced. The compressor blade includes 17 stages, and an obtained air compression ratio is 18.

Further in the present example, an Ni-base super alloy is used in the first-stage turbine nozzle 81 and first-stage turbine blade 51 of the gas turbine. Depending on a combustion gas temperature, a polycrystalline cast material is used in 1300°C class, and a monocrystalline cast material is used in 1500°C class. In the monocrystalline cast material, an Ni-base super alloy is used containing, by weight percentage, 4 to 10% Cr, 0.5 to 1.5% Mo, 4 to 10% W, 1 to 4% Re, 3 to 6% Al, 4 to 10% Ta, 0.5 to 10% Co, and 0.03 to 0.2% Hf. The equivalent alloy containing 10 to 15% Cr is used in the polycrystalline cast material.

The second-stage turbine nozzle and third-stage turbine nozzle are constituted of the Ni-base super alloy containing, by weight percentage, 21 to 24% Cr, 18 to 23% Co, 0.05 to 0.20% C, 1 to 8% W, 1 to 2%

Al, 2 to 3% Ti, 0.5 to 1.5% Ta, and 0.05 to 0.15% B. These nozzles include an equiaxed structure obtained by usual casting.

The Ni-base super alloy is used in the second-stage turbine blade 52 and third-stage turbine blade 53. Depending on the combustion gas temperature, the polycrystalline cast material is used in the 1300°C class, and a directionally solidified prismatic Ni-base super alloy cast material is used in 1500°C class. Either material is constituted of the Ni-base super alloy containing, by weight percentage, 5 to 18% Cr, 0.3 to 6% Mo, 2 to 10% W, 2.5 to 6% Al, 0.5 to 5% Ti, 1 to 4% Ta, 0.1 to 3% Nb, 0 to 10% Co, 0.05 to 0.21% C, 0.005 to 0.025% B, 0.03 to 2% Hf, and 0.1 to 5% Re. The blade of the directionally solidified prismatic Ni-base super alloy is obtained by entire solidification in one direction toward a dove-tail direction from the tip end.

In the present exceeding, the toughness is high even with strength enhancement and heating embrittlement. Accordingly, since especially the material temperature of the turbine disc can be set to be high, the above-described cooling can be reduced. Furthermore, the thickness or diameter of the above-described member for use can be reduced, reduction in weight is achieved, and start properties are enhanced.

By the above-described constitution, a gas turbine generally balanced with high reliability is

obtained. It is possible to achieve a gas turbine for power generation, in which a natural gas, light oil, and the like are used as fuels for use, a gas inlet temperature into the first-stage turbine nozzle is 1500°C, a metal temperature of the first-stage turbine blade is 900°C, an exhaust gas temperature of the gas turbine is 650°C, and a power generation efficiency is 37% or more in LHV indication. This also applies with the gas inlet temperature into the first-stage turbine nozzle of 1300°C.

Moreover, in the present embodiment, it is possible to constitute a multiaxial combined cycle power generation system including a combination of one gas turbine and one high/medium/low pressure integral steam turbine having a steam inlet temperature into the first-stage turbine blade at 566°C. Each turbine includes a power generator. A higher power generation efficiency can be obtained.

According to the present invention, a high-efficiency high-temperature gas turbine is obtained in which a creep rupture strength and an impact value after heating embrittlement required especially for a gas turbine in a gas temperature class at 1300 to 1500°C are high. Furthermore, the present invention can also be applied to a turbine stacking bolt, turbine spacer, and distant piece exposed at a high temperature in a heating embrittlement range. Therefore, according to the present invention, since a combustion temperature

and member temperature of a gas turbine power generation plant can be raised, the cooling in a high-temperature section can be reduced. Further, on the other hand, a rotation section can be reduced in weight, and therefore further high efficiency is achieved. Moreover, it is possible to save a fossil fuel and to reduce a generated amount of exhaust gas and to contribute to global environment preservation.

It should be further understood by those skilled in the art that although the foregoing description has been made on embodiments of the invention, the invention is not limited thereto and various changes and modifications may be made without departing from the spirit of the invention and the scope of the appended claims.